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Control logic and strategy for emergency condition of piston type energy recovery device

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HIGHLIGHTS

• The flexibility of FS-ERD is proved under different pressures and capacities.
• An optimized PLC control strategy with fault tolerance module is developed.
• The optimized PLC controller can deal with the emergency condition of the FS-ERD.
• Reliability of the FS-ERD is demonstrated under simulated emergency condition.

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ABSTRACT

Piston type energy recovery device (ERD) commonly depends upon the concerted actions of magnetic sensors and PLC controller to realize the energy recovery function. For ensuring operational stability and flexibility of the device, signal control mode is basically adopted in the standard PLC controller. However, as a typical emergency condition of the signal control mode, failure of the magnetic sensor may bring on function loss of the mode, which imperils the operational safety of the ERD and even the RO system. So in this paper, an optimized PLC control strategy with fault tolerance module is developed to resolve the possible control problem of piston-type ERD. The experimental results indicate that the optimized PLC control strategy can maintain reliable under simulated emergency condition of magnetic sensor failure.

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1. Introduction

As is known, the seawater reverse osmosis is a pressure-driven membrane process and requires a tremendous amount of energy for pressurizing raw seawater [1–3]. Ultimately, most of the pressure energy is contained in the high pressure brine flowing out of the RO modules. In order to efficiently recover the pressure energy of high pressure brine, isobaric energy recovery devices (ERDs) have been developed and essentially incorporated in the RO plant design [4,5].

The piston type ERD is one representative of the isobaric devices, which comprises three main parts, the switcher (also named multiple-function valve), two cylinders and a check valve nest [6,7], and commonly follows signal control mode to realize its energy recovery function. The signal control mode is actually a collaborative unit of magnetic sensors and PLC control system. Under the mode, the magnetic sensors are used to monitor the position of piston in each cylinder and submit the position signal to the PLC controller to direct the switch of pressurization and depressurization processes of the device in real time.

Commercial products of piston type ERD are known as DWEER of Flowserve and SalTec DT of KSB [8–10], which have demonstrated excellent operational performances, such as high energy recovery efficiency and reliability, in industrial seawater reverse osmosis plants [11–15]. However, the advantages of the piston type ERD, especially the good operational flexibility under condition of variable pressures and different capacities brought by the adoptive signal control mode have rarely been displayed and reported in literatures [16–18]. It is the first task of the paper to test and evaluate the operational flexibility of the ERD under signal control mode.

As an important component of signal control mode, the magnetic sensor links up the ERD with the standard PLC control system and plays an indispensible role in the cyclical phase switch of the device. Therefore, if the magnetic sensor incurs failure, not only the function of signal control mode will be lost, but the safety of piston type ERD or even the RO system will be imperiled. In order to ensure the highest possible online availability of ERD in such emergency situation, some

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measures should be taken into account accordingly. In the paper, an optimized PLC control strategy is developed, which not only comprises the basic signal control mode, but also contains a fault tolerance module which can preferably satisfy the stochastic failure and remediation demands of magnetic sensors. The second task of the paper is to evaluate the availability and stability of the optimized PLC control strategy under emergency condition. The above two tasks are carried out on the basis of self-developed ERD product named FS-ERD and the corresponding RO emulating platform [19–21].

2. Brief description of the FS-ERD

As seen in Fig. 1, the FS-ERD consists of three main parts: the fluid switcher (FS) on the brine side, the check valve nest on the seawater side, and the two cylinders between them. The fluid switcher driven by a motor is used to guide the high pressure brine and depressurized brine to flow into and out of the cylinders periodically. It is featured with two working phases (phase I and II) which correspond to the pressurization process and depressurization process of cylinder 1 respectively. The check valve nest controls the import of raw seawater and the export of pressurized seawater. Open or close of the check valves is automatically directed by the pressure conditions in the cylinders.

Fig. 1 gives the flowing directions of FS-ERD at working phase I, wherein the high pressure brine flowing into cylinder 1 through the fluid switcher directly pressurizes the pre-filled raw seawater and drives pressurized seawater out of cylinder 1 and the check valve nest. At the same time, the raw seawater flows into cylinder 2 through the check valve nest and discharges the depressurized brine out of cylinder 2 and the fluid switcher. When the pistons in the cylinders pass through primary magnetic sensors of S2 and S3 respectively, the position signals of pistons will be detected and submitted to the standard PLC system to direct the fluid switcher switching from phase I to phase II. In this condition, the working processes will be exchanged in two cylinders, meaning that depressurizing process is carried out in cylinder 1, and pressurizing process in cylinder 2.

Likewise, the fluid switcher will be directed back to phase I again when the pistons in the cylinders pass through primary magnetic sensors of S1 and S4. The double alternation of the two working phases constitutes one cycle of the energy recovery process and the above control mode is defined as signal control mode. Under the control mode, continuity of the process relies dominantly on the concerted actions of magnetic sensors and the standard PLC controller. In the figure, four auxiliary magnetic sensors (S1′, S2′, S3′ and S4′) are adopted in each cylinder ends. The four auxiliary sensors don't participate in the control of FS-ERD directly and are used only to judge working state of the primary magnetic sensors (S1, S2, S3 and S4).

3. Test stand and the PLC control strategy

To evaluate the operational performance of the FS-ERD, especially in emergency conditions, an emulational RO desalination test stand is set up as presented in Fig. 2 [22,23]. The flow diagram of the stand is similar to the actual RO system and owns feed-water pump (Grundfos, CR32-3-2), high pressure pump (Danfoss, PAH80), booster pump (Sulzer, ZF50-3315) and FS-ERD (in the red box). The RO modules whose pressure loss is simulated by a shutoff valve are not installed in the test stand. Here, the check valve nest of the FS-ERD is displayed in parallel (different from Fig. 1) in order to present the pipe layout in seawater side more clearly.

3.1. PLC control strategy

As one of the core parts of the FS-ERD, the PLC control system not only determines the switch principle of the device directly, but also affects the operational performance of FS-ERD indirectly. Therefore appropriate control strategy should be designed to ensure continuous operation of FS-ERD both in normal condition of magnetic sensor at work and emergency condition of magnetic sensor failure.

In this paper, an optimized PLC control strategy is developed which innovatively integrates the basic signal control mode introduced in Section 2 and an auxiliary time control mode. The time control mode owns counterpart function as signal control mode and depends on specified time interval instead of the signal from the magnetic sensors to direct the principal switches of the FS-ERD. Both of the control modes can satisfy the operating requirements of FS-ERD; however, only one mode is performed at a time according to the operating requirement.

As shown in Fig. 3, the two control modes will be exchanged to direct the operation of FS-ERD according to the working state of primary magnetic sensors. Due to the need of PLC controller, Fault Detection module is incorporated to judge the working state of primary magnetic sensor according to its inductive signals. If the signals from two diagonal primary magnetic sensors can't be detected within normal cyclical switch time plus the judgement time under signal control mode, the primary magnetic sensor is determined to be failed and the signal control model will be changed to time control mode immediately. The Fault Isolation is following with the Fault Detection to confirm the reasons resulting in the abnormal signal detection of magnetic sensors. If the signals from the primary magnetic sensors cannot be detected while signals from auxiliary sensors can still be received properly, fault of the primary sensor could be absolutely determined. If signals from auxiliary sensors also cannot be received properly, it's determined to be false positives which need to be confirmed and precluded artificially.

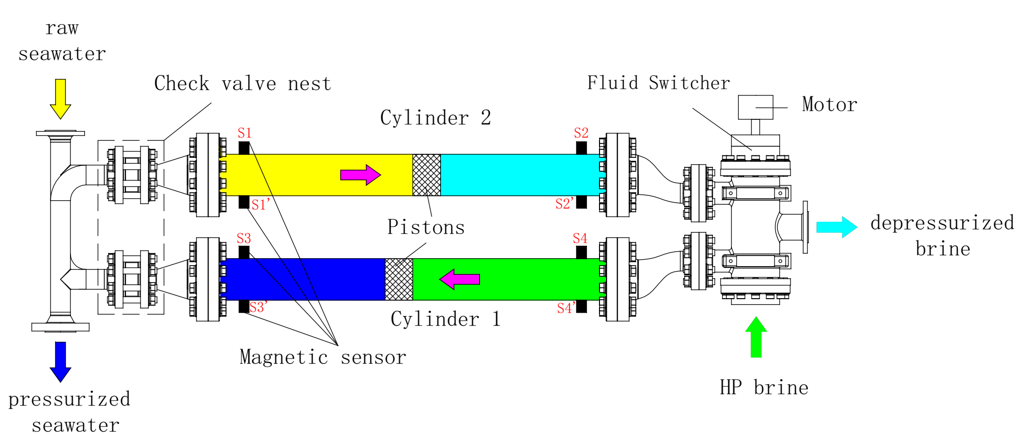

Fig. 1. Schematic representation of FS-ERD at working phase I.

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